Space Weather Technical Forecast

Issued on Thursday, 14 December 2023 at 12:35 Local

This technical forecast provides a four-day assessment of space weather events. The probabilities stated below are for reaching or exceeding the given levels. For more information about space weather impacts please see the Met Office Space Weather Scales https://www.metoffice.gov.uk/weather/learn-about/space-weather/uk-scales

Space Weather Forecast Headline: R2 observed, further instances Likely. Peak Chance G1 16 December from CME arrival. Further CME(s) awaiting imagery.

Analysis of Space Weather Activity over past 24 hours

Solar Activity: Solar activity, as recorded by GOES16 and 18 rose to Moderate in the past 24 hours, with an early C9.8 from the southwest limb (and perhaps Ex-AR3511) separated by a span of minimal flare activity (in low C-class) until a large, multiple-stage peak M5.8 from AR3514 at 14/0744UTC in the western solar hemisphere.

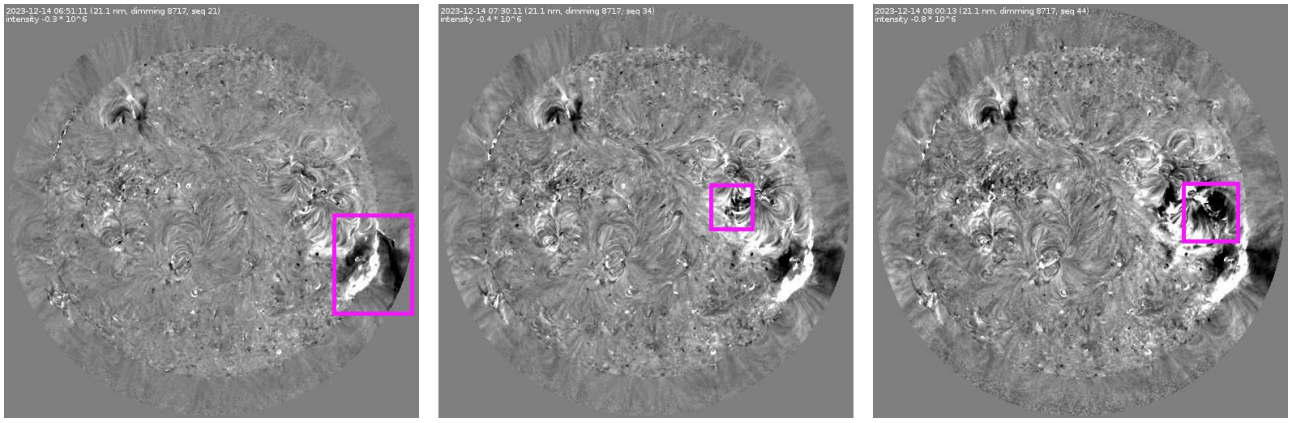

Figure 0: SIDC ROB-processed time integrated AIA211 extreme UV imagery, showing mulitiple events leading into the 0744UTC M5.8 from AR3514. Any CMEs from these events are awaiting imagery for analysis.

The sunspot region responsible for the M5.8 was the large, complex and rapidly growing AR3514, which at the time had attained Dac/Beta-Gamma-Delta configuration, with a notable increase in penumbral area across most of its constituent spots, and with at least one Mt Wilson delta having developed in its central portion as the constituent penumbrae were forced into close proximity. The M-class flare itself was potentially sparked by a chain of events that started with a prominence eruption on the southwest limb around 14/0600UTC, which then generated an EIT wave propagating radially. This potentially destabilised AR3514, with a modest flare in its trailer generated on passage of the EIT wave at 14/0720UTC, which in turn perhaps primed the larger event of the M5.8 from its leading group.

The above sunspot region was one of eight on the current disc, although this does include four unipolar groups. Of most interest were AR3514, but also AR3520 and AR3519, which, while simpler, also saw marked proliferation of spots, spreading tendencies and development of penumbrae to reach Dsi and Dso/Beta classifications respectively.

At least three separate Coronal Mass Ejection (CME) events were visible in coronagraph imagery

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of the last 24 hours. Firstly, a westward-directed event from narrowly over the limb during the UTC afternoon of 13 December. This has been analysed and bears no impact on the forecast Secondly, a low-latitude, apparently far-sided southeast-heading CME during the same UTC evening. No reliable measure of the source region is available for this part of the disc, and the event appears below the ecliptic in any case. Thirdly, the 14/0600UTC prominence eruption became visible in the current UTC morning's imagery heading apparently southwest. This feature has yet to be analysed, but may tentatively bear some form of glancing incidence later in the forecast period. It is very possible from evidence such as AIA211 dimming that the M5.8 event has also generated a CME along a more Earth-directed track that has yet to appear. These final (two?) events are of most interest and further imagery is awaited. At the time of writing no new CMEs were confirmed as Earth-directed.

Solar Wind / Geomagnetic Activity: Solar winds, as observed at L1 by ACE and DSCOVR were initially at Background levels, but saw a step-wise enhancement in many measures that first occurred in a data gap between 13/2130-2230UTC. The causative event associated with this probable transient is not known, but its tenure was brief, with a resumption of Background winds by the end of the 24-hour reporting period.

The solar wind speed initially showed a declining trend within Background from 375 to 325km/s, before climbing back to 375 after roughly 12/2100UTC. The solar wind density, which had previously fallen from around 10ppcc to single figures, rose to a peak near 15nT at 13/2300UTC before resuming its earlier decline. The IMF was perhaps the most marked solar wind measure: rising from an early stable trend near 8nT to peak at 15, with the north-south component showing a heavy anti-aligned bias and a range between +3 and -13nT. The phi angle was positive (away from the Sun).

The net effect of the above solar wind measures was for rising geomagnetic activity, from initial Quiet levels to a provisional peak of Kp '5-' in the 03-06UTC interval, as reported by BGS.

Energetic Particles / Solar Radiation: GOES16 high energy (greater than 10MeV) proton flux remained unmoved at Background levels in the 24-hour period, despite the M5.8 flare from a nominally exposed position.

GOES16 high energy (greater than 2MeV) electron flux was also at Normal Background levels. The 24-hour fluence was below the Active threshold (1e8 integrated pfu). The observation at 14/0001UTC was 1.39e6 integrated pfu.

Four-Day Space Weather Forecast Summary

Solar Activity: Further M-class flares are considered Likely, with a Slight Chance of X-class, primarily from AR3514. No sunspot regions leave the disc in the period. The oncoming far eastern limb is heavily populated with potential returning sunspot regions, however any contribution from these remains to be seen.

Solar Wind / Geomagnetic Activity: There is currently one CME in the forecast - that from 13 December from AR3514, which is currently expected to arrive on day 3 (16 December) during the UTC morning with low confidence. Further potential CMEs from 14 December are awaiting imagery for analysis.

Otherwise, CH79 is due within the current UTC day, easing into the UTC weekend. Winds are likely to peak at Elevated levels, at around 500-550 km/s, however confidence is currently low in both timing and peak wind strength.

There is a rising Slight Chance of Minor Geomagnetic Storm G1 conditions in the next 24 hours, then peaking with an eventual Chance of a spell of Active to G1 Minor storms on day 3 (16

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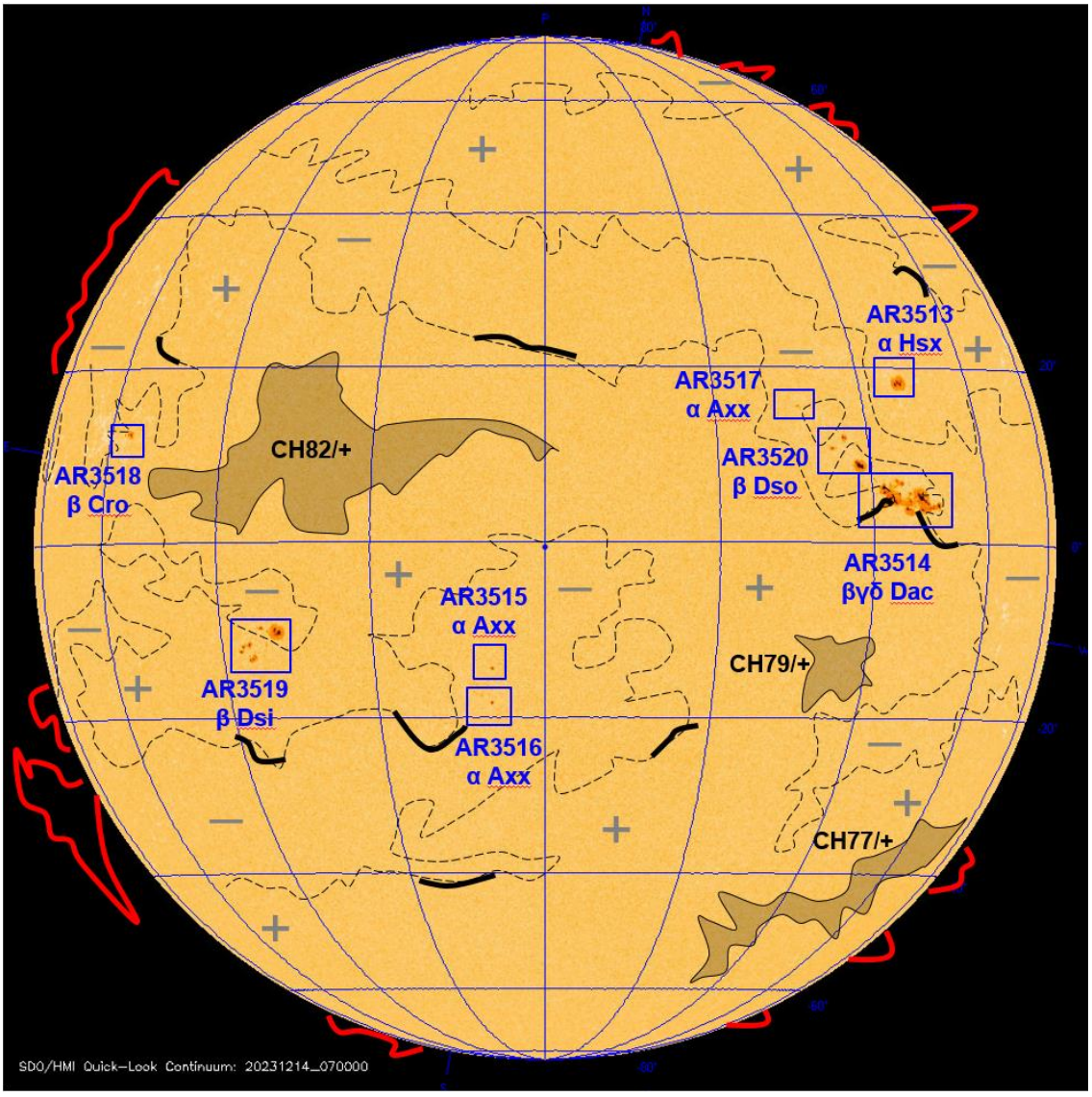
December) from any CME arrival, before reverting to Quiet later in the coming UTC weekend.

Energetic Particles / Solar Radiation: GOES16 high energy proton flux carries a now increased risk of S1 in the first 12 hours given the M5.8 from the western solar hemisphere at 14/0744UTC, although this now appears relatively unlikely to be associated with any enhancement. Despite the possible lack of proton enhancement with this event, the daily risk is nevertheless slightly higher than previously advertised given the new scale of X-ray activity in a prone location from AR3514.

High energy electron flux, as observed by GOES16, is currently at Normal Background. The timing and strength of solar winds enhancement from CH79/+ is low confidence, but is currently expected to be relatively weak, occurring later on day 1 or day 2 (14-15 December). This will limit the extent of any increased flux, perhaps briefly touching High on day 2 and into day 3 (15-16 December). The arrival of a CME on day 3 (16 Dec) is then likely to return flux to Background.

Figure 1. Solar Analysis Valid 14/0700UTC.



Key: Filament ___ , Prominence ___ , Magnetic Field Line - - - , Polarity +/-, Coronal Holes: Grey shaded area CHxx +/-, Sunspot groups 25xx - Mt Wilson α-β-βγ-βγδ and Zurich-McIntosh Axx etc.

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Geomagnetic Storms:

There is currently one CME in the forecast - that from 13 December from AR3514, which is currently expected to arrive on day 3 (16 Dec) during the UTC morning with low confidence. Further weak CMEs have been observed from AR3514, including from the C9.0 flare at 12/0350UTC. However these are either narrow, faint or very low confidence, and considered unlikely to have any noticeable impact. In addition to the above, further potential CME(s) from 14 December are awaiting imagery for analysis.

The past 24-hour period saw unexpected transient influence around 13/2100UTC, culminating in a solitary interval of G1 before easing. The cause of this event is uncertain, but the slow associated speed perhaps puts it as occurring around the very start of the current UTC working week. Interestingly, this does not meaningfully manifest at STEREO A MAG or PLASTIC, perhaps implying extreme glancing incidence of Earth from an originating event in the eastern solar hemisphere.

The coronal hole-driven forecast is otherwise for CH79's fast wind to arrive in the next 24 hours (14 into 15 December), perhaps peaking around 500-550km/s, Confidence is low in the timing and peak wind speeds however, due to the non-persistent nature of this coronal hole, and MOSWOC Enlil's recent overestimated influence from CH77/+ in the far south - with solar wind speeds around 100-150km/s too fast in model-space around midweek.

Influence from the unexpected transient has now likely peaked, meaning that there is now again an increasing Slight Chance of G1 with the arrival of CH79/+ in the first 24 hours. This should then give way to the 13 December CME into the UTC weekend, with this in turn waning to largely Quiet conditions by the end of the four days. CH82 is provisionally assessed as being too far eastward to feature in this forecast period - as with previous rotations - but it is noted that it appears to have a promontory that extends a long way westward which may yet prove relevant (i.e. bringing this feature in early).

Geo-Magnetic Storm Probability (Exceedance)	Level	Past 24 Hours (Yes/No)	Day 1 (00-24 UTC) (%)	Day 2 (00-24 UTC) (%)	Day 3 (00-24 UTC) (%)	Day 4 (00-24 UTC) (%)
Minor or Moderate	G1 to G2	Yes	10	10	25	1
Strong	G3	No	1	1	1	1
Severe	G4	No	1	1	1	1
Extreme	G5	No	1	1	1	1

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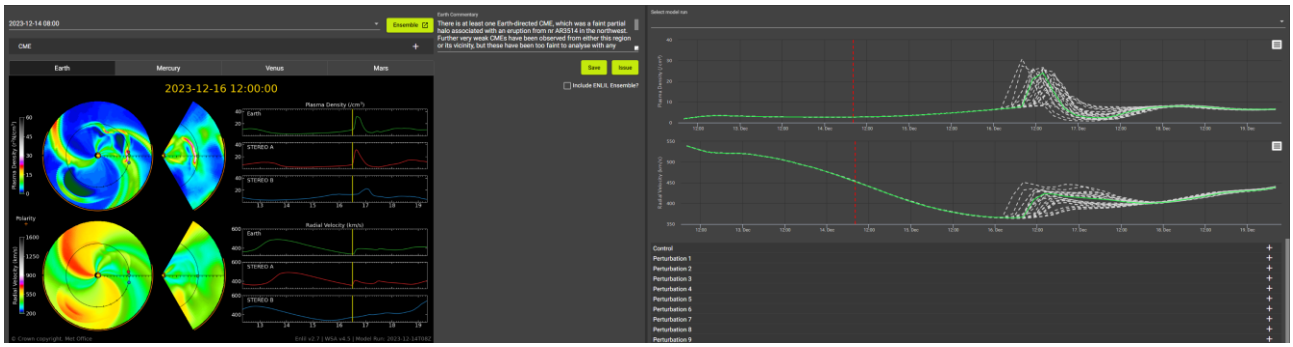
Geomagnetic Activity - Earthbound Coronal Mass Ejections

Date/time 21.5R (UTC)	Halo: Full or Partial	Source	Source Location	Estimated Speed	Estimated Arrival Time	Comments
13/0555	Partial	Filament and C2.8 flare	AR3514	530 km/s	16/0800 +/- 12 hours	Low confidence – still under analysis. Faint in imagery

Figure 2: Latest (14/0800UTC) MOSWOC Enlil run and ensemble, showing the 13 December CME as arriving around the middle of the UTC day. This is slightly later in the earlier forecast spread, perhaps the result of later runs of Enlil adjusting for the erroneous earlier inclusion of the CH77/+ fast wind emanating from the southern solar hemisphere, and absent from L1. On balance, the forecast is not substantially different, with G1 still a chance in the same UTC day, perhaps centred around midday.



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Radio Blackouts - X-Ray Flares:

The current Earth-facing side of the Sun appears to be showing two main areas of development - with significant upwelling and development of active regions near the solar equator at 50W (AR3514 and 3520) and 30E (AR3519). Sunspots overlying these areas have grown significantly in penumbral area in the past 24 hours, with all now Zurich D-groups, and with Ar3514 reaching Dac/Beta-Gamma-Delta complexity.

Because of the observed growth and spreading trends that are not accounted for elsewhere in the whole-disc forecast, the probabilities of M and X class events have both been revised upwards from raw values, with all the sunspots responsible remaining on the front side to persist this risk through the end of the coming week and over the weekend.

Potentially adding to the daily risk of flares in the period are the returning Carringtons for numerous sunspot regions in the four days, with some recent far-southeastern CMEs perhaps evidence for some survivals here at least, although any uptick remains to be seen.

X Ray Flares Probability	Level	Past 24 Hours (Yes/No)	Day 1 (00-24 UTC) (%)	Day 2 (00-24 UTC) (%)	Day 3 (00-24 UTC) (%)	Day 4 (00-24 UTC) (%)
Active	R1-R2 M Class	Yes	60	60	60	60
Very Active	R3 to R5 X Class	No	10	10	10	10

Figure 3: Past 72 hours' flare locations of C-class and above (recorded by PROBA2, white pixels), showing relative dominance of AR3514. Processing courtesy of SIDC ROB.

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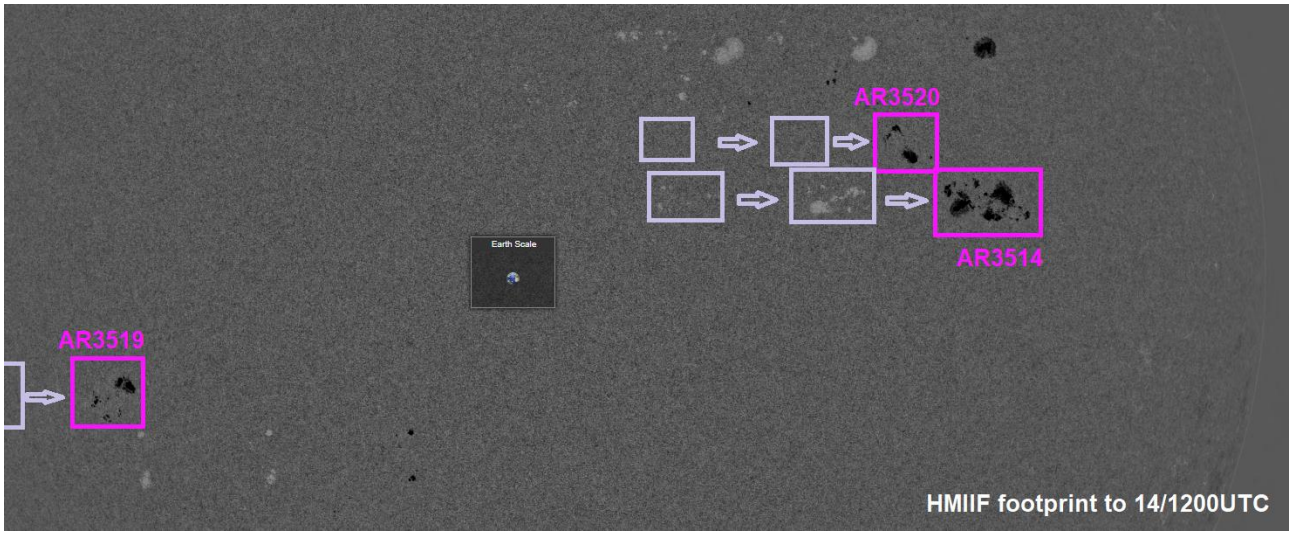
Figure 4: Helioviewer.org-generated HMIIF difference imagery for 24-hour intervals covering past 48 hours, ending in the black footprints of 14/1200UTC. Note the pronounced growth in AR3514 especially, but also AR3519 and 3520, which have grown from plage inside 24 hours.



Solar Radiation Storms - (High Energy Protons):

The high energy (greater than 10MeV) proton flux observed by GOES16 is currently at Background levels. Because of AR3514's 14/0744UTC flare, there is perhaps still a residual slightly increased Slight Chance of S1, although the odds are fading given the intervening time, and there was no obvious particle noise on Lasco imagery (for example).

From here, the resumption of significant X-ray events as AR3514 nears the west limb has led to a slight revision upwards of the background risk of S1 events - even in the absence of any in this particular case. The subsequent slight daily rise in risk with AR3514 moving westward is not sufficiently different from a daily 10% risk to show in the tables, before an eventual decrease then follows into the new working week UTC.

Radiation Storms Probability (Exceedance)	Level (cm^{-2} sr^{-1} s^{-1})	Past 24 Hours (Yes/No)	Day 1 (00-24 UTC) (%)	Day 2 (00-24 UTC) (%)	Day 3 (00-24 UTC) (%)	Day 4 (00-24 UTC) (%)
Active	**≥ S1**	No	15	10	10	10
Very Active	**≥ S3 ***	No	1	1	1	1
* S3 ≥ 10 MeV ≥ 1000 pfu and / or ≥ 50 MeV ≥ 10 pfu. (pfu = $cm^{-2}sr^{-1}s^{-1}$)						

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High Energy Electrons Event (≥ 2MeV):

High energy electron flux, as observed by GOES16, is currently at Normal Background. The timing and strength of solar wind enhancement from CH79/+ is low confidence, but is currently expected to be relatively weak, occurring later on day 1 or day 2 (14-15 December). This will limit the extent of any increased flux through the Van Allen Belts, with observed flux probably rising to Moderate, and perhaps briefly touching High on day 2 and into day 3 (15-16 December). The arrival of a CME on day 3 (16 Dec) is then likely to return flux to background, although this also means that MOSWOC REFM guidance cannot be followed beyond this stage. The associated 24-hour fluence is expected to remain below the Active threshold, with the scope of any post-CME rebound probably modest given its stature.

GEO Electron Environment	**Level (cm^{-2} sr^{-1} day^{-1})**	**Past 24 Hours (Yes/No)**	**Day 1 (00-24 UTC)**	**Day 2 (00-24 UTC)**	**Day 3 (00-24 UTC)**	**Day 4 (00-24 UTC)**
Probability (Exceedance)			**(%)**	**(%)**	**(%)**	**(%)**
Active	**≥ 2 MeV ≥ $1x10^{8}$**	No	1	1	5	20
Very Active	**≥ 2 MeV ≥ $1x10^{9}$**	No	1	1	1	1

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